Vision-based Navigation Solution for Soft and Precise Landing on Mars

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All the space you need

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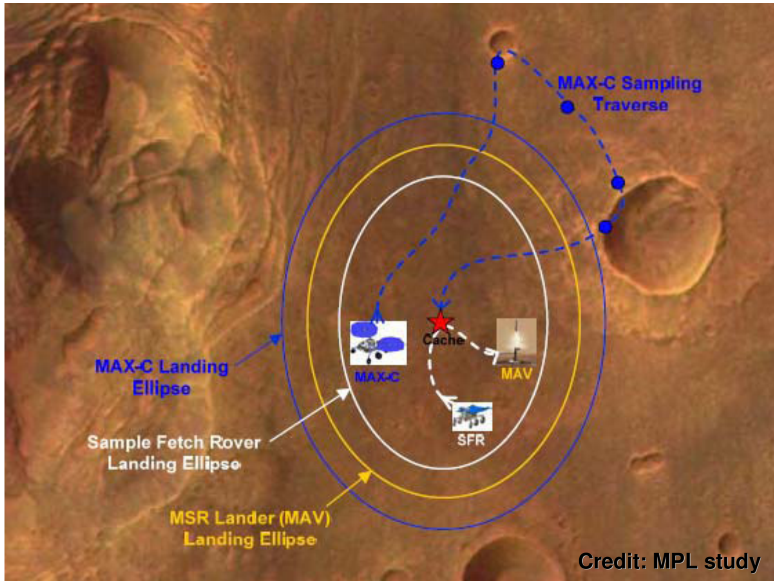
Detailed agenda

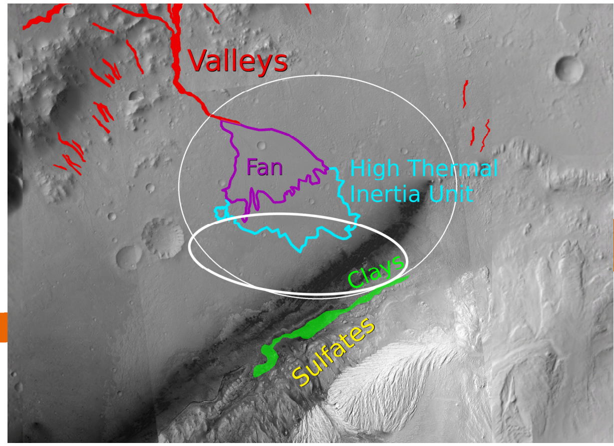
- Goals and stakes
- Navigation system
  - Relative navigation for landing
  - Absolute navigation for approach
  - Absolute navigation for landing
  - Sensor suite
- Performance assessment
  - Navigation error budget
  - Detailed results
- Conclusion and future work

Credit: ESA/DLR/FU Berlin

Goals and Stakes (1/2)

- Mars precision landing requirements have become more stringent
  - Mission planning of MSR
    - MPL 10km, close to MAV and sample cache
  - Scientific interests constraints
    - MSL 20x7 km ellipse, 150x20 km for MER
    - Guided entry implemented
  - Main remaining error contributors:
    - Precision of injection (ΔDOR, Doppler, range)
    - Error accumulated during re-entry (inertial)

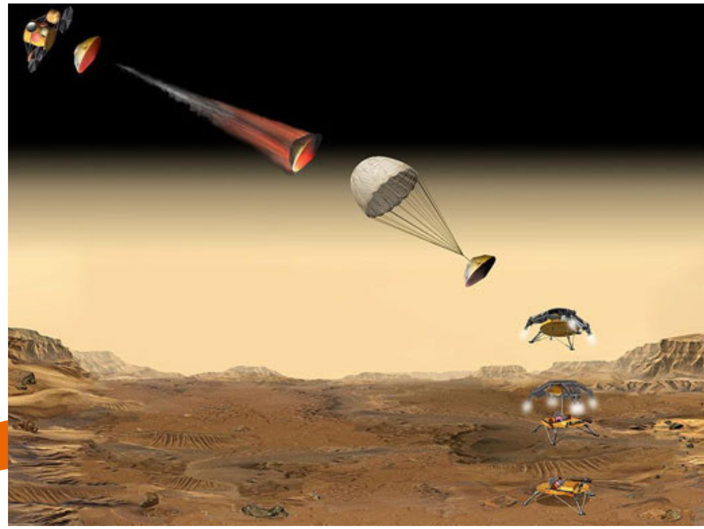




Goals and Stakes (2/2)

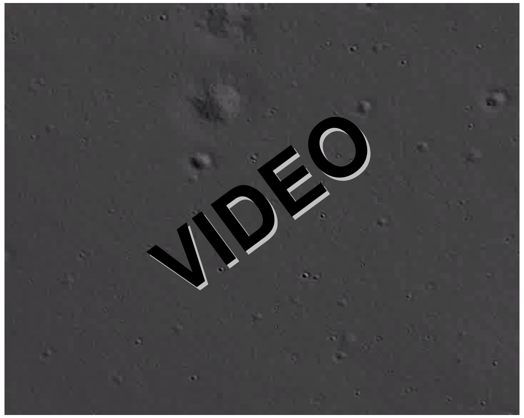
Vision based navigation

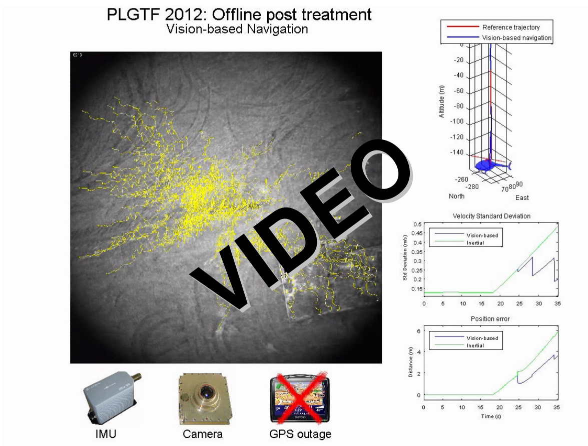
- Experience of Astrium in relative vision-based navigation systems
  - Inherited from ESA NPAL study
  - Applied to MPL
  - **Autonomous** solution, guarantees **soft landing**, but not precision (no direct observation of position in planetary frame)
- Investigation of vision-based navigation for **precision**
  - Improvement of system for main error contributors
  - Absolute navigation in **approach**
  - Absolute navigation during **landing**
- Navigation error budget presented here



Navigation system (1/6)

- **Relative** navigation for **landing**
  - Based on NPAL (ESA study) algorithms: feature point extraction and tracking
  - Algorithms validated on PLGTF experiment images (NPAL camera and IMU flown on UAV, with UFS algorithms: NPAL evolution)





  - Provides:
    - velocity and attitude estimates on all axes → Reduced position drift
    - an estimate of altitude based on feature point depth
    - but no lateral position measurement wrt landing area

Navigation system (2/6)

Absolute navigation for Approach principle

- LoS towards a priori known patches on the visible Mars globe
  - Importance of image processing
  - LoS converted to inertial frame with Attitude Determination System
- Different LoS hybridized in dynamic filter (Kalman)
- Derivation of position in inertial frame or wrt Planet

Absolute navigation image processing for Approach

- Patch matching techniques used for Astrium Earth observation satellites
- Suitable for embedded coding:
  - Algorithms core similar to already embedded artificial vision techniques
  - Image database textures require limited disk space
- A variety of fast processing are applied (DEM correction, Mars ellipsoid, atmosphere transmission, etc…)

Navigation system (3/6)

- **Absolute** navigation simulations
  - Use of MSL approach trajectory
  - An in-house high fidelity planetary image simulator has been developed : Surrender
    - Full Mars with a 100m resolution referenced texture
    - A variety of effects are simulated: atmosphere layers, reflectance models, dust clouds, frost, elevation, illumination conditions (including shadows casting), etc.
    - Rendered textures are from real missions (MGS, MRO, Viking) extracted from NASA PDS. Different textures for approach images and on-board patches

Navigation system (4/6)

- **Absolute** navigation for **Landing** principle and image processing
  - Identification of descent images in a reference map the size of initial uncertainties
  - Algorithm designed for Mars specificities :
    - Initial position uncertainty of the order of the camera FoV projected on ground
    - Large uncertainty on altitude and scale at initialization
  - Image processing robust to large scale uncertainties
    - Altitude can be estimated by the image processing technique
    - Relative navigation outputs (attitude, altitude) allow enhancement of the absolute navigation algorithms

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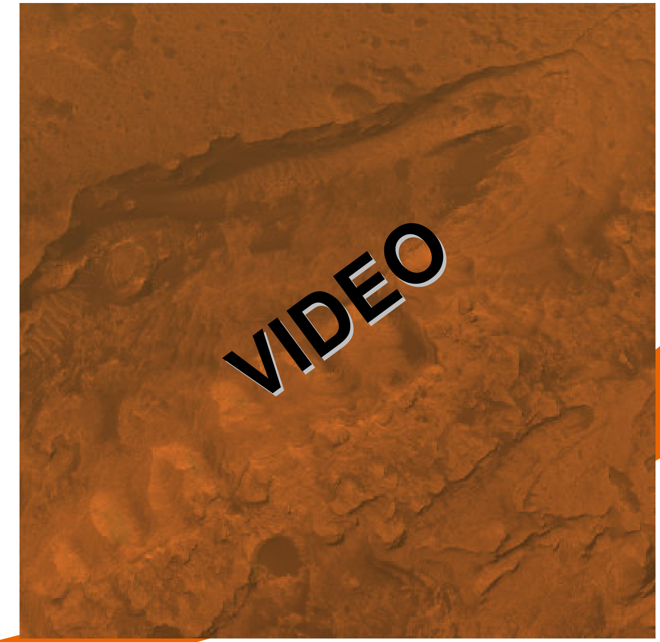
Navigation system (5/6)

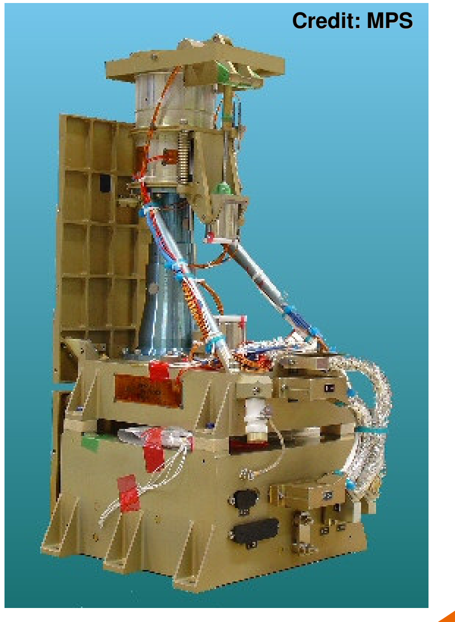
- **Absolute** navigation for **Landing** simulations
  - MPL trajectory above Gale Crater
  - Use of Pangu interfaced with Astrium tools for real terrain management.
    - Real DEM and texture are used
    - Texture projected on DEM using Pangu
    - A variety of terrains can be imported and simulated
  - Advantages :
    - Database map and descent images are based on different sources (ex: S/C descent images from MRO, Database map from Viking)
    - Numerous environment-related parameters can be tuned for a fair robustness assessment

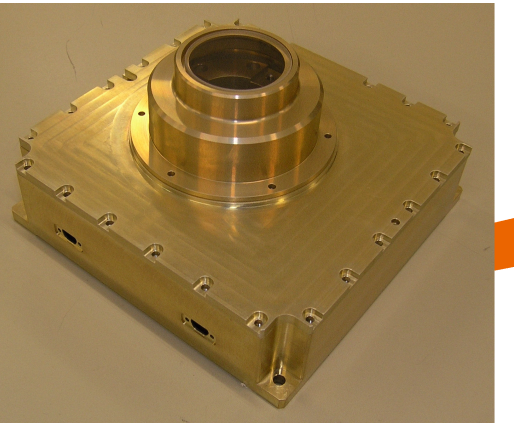


Navigation system (6/6)

Sensor suites

- 2 Jena Astro APS STR, 1 LN 200 IMU
- NAC (for approach):
  - 3 degree FoV, 1024x1024 detector
  - Inspired from Dawn framing camera
- WAC (for landing): NPAL camera
- Radiofrequency tracking (1 update/day):
  - 21.6 km (3σ) assessed for MSL with Doppler only
  - Better than 2km (3σ): MSL baseline with ΔDOR





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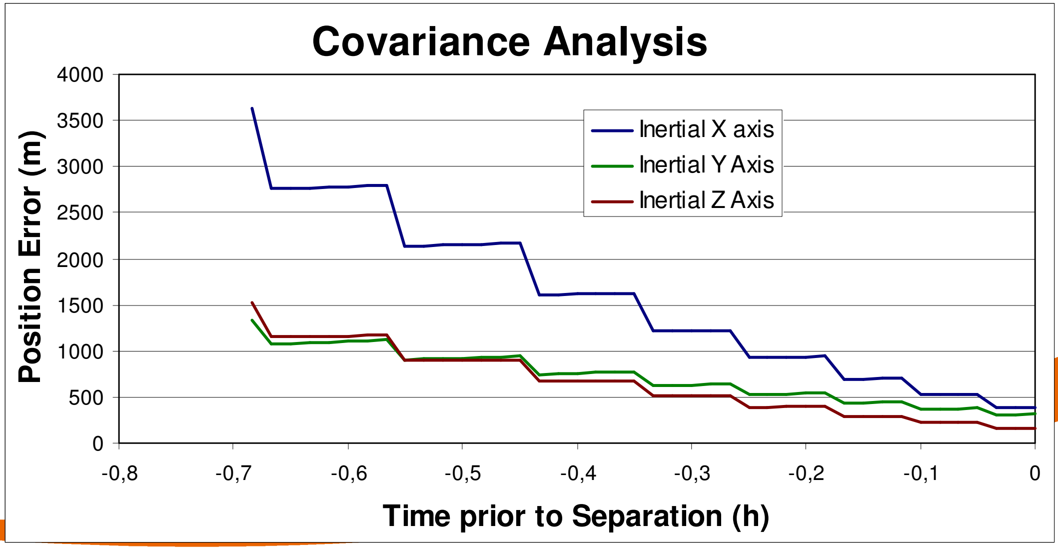
Performance assessment (1/2)

- Navigation error budget (3σ, worst axis), using all functions

Event	Present system	MPL results	Comments
Carrier separation	900 m	2100 m	MPL: MER+50%, B-plane, ΔDOR
Front shield jettison	3600 m	4500 m	Simple propagation with IMU, to be refined
Thruster activation	75 m	5200 m	No absolute navigation used for MPL
Touch down	**58 m**	5200 m	Abs. nav. stopped at 400m ASL, relative still operating

- Detailed results for Approach (last day)

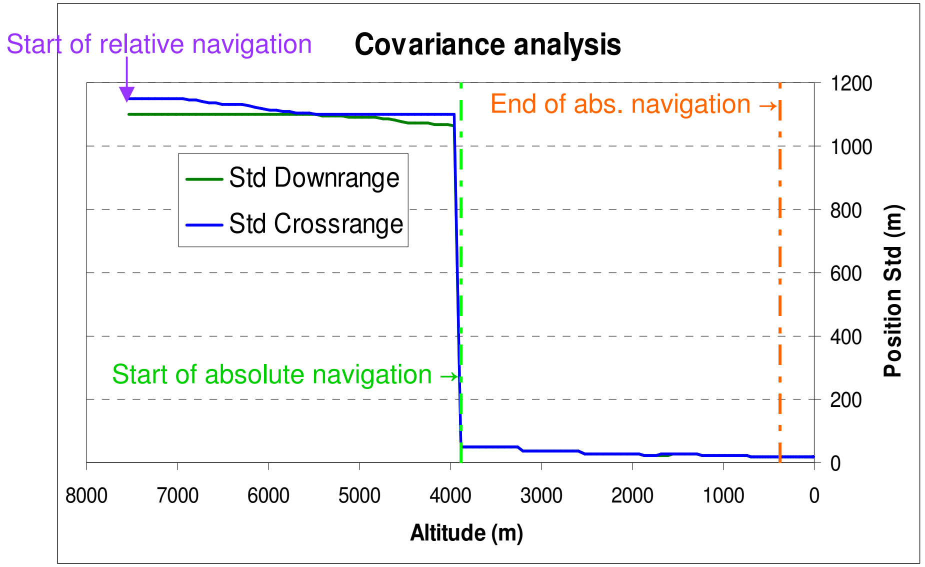


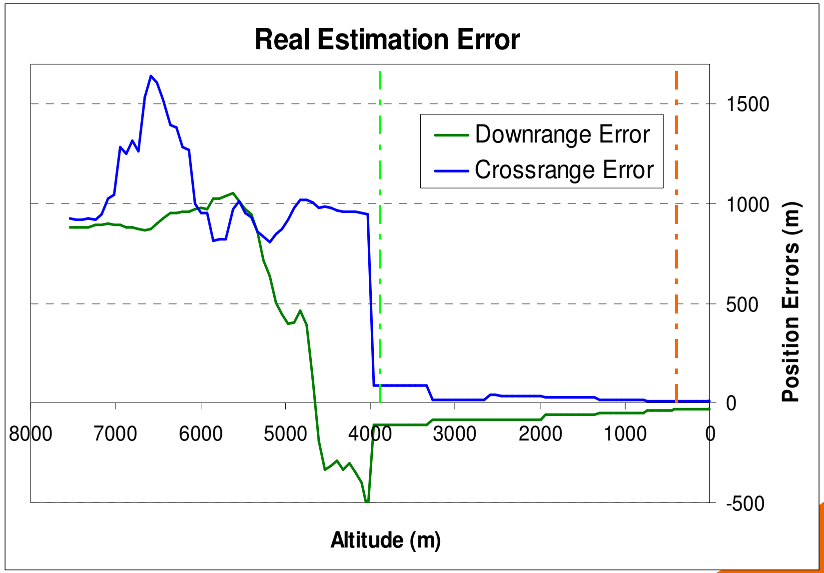
Full performance is reached in the last hours

Performance assessment (2/2)

Detailed for Landing

- Absolute navigation (taking into account the enhanced accuracy at entry)





- Relative navigation
  - Altitude error better than 4m (dropship concept robust to this error)
  - Velocity error: 0.3 m/s vertical, 0.1 m/s horizontal (3σ) at touchdown

Conclusion and future work

- Vision-based navigation: a relevant solution for Mars landing
  - Improvement of navigation error before EIP
  - Pin-point landing possible with very good accuracy at touchdown
  - Soft landing requirements met
  - Autonomous, and light weight solution
  - MREP camera TRP to assess robustness
- Completion and refinement of results
  - Results are still preliminary (with representative images)
  - Full performance analyses (Monte Carlo) beyond covariance
  - Different scenarios, cases, sensitivity analysis
- Full GNC integration and closed loop, online IP
  - Assessment of total delivery error

Thank you for your attention !

Any questions ?